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**BUILDING COMPLEX SIMULATIONS RAPIDLY
USING MATRIX_x -- THE SPACE STATION REDSIGN**

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BUILDING COMPLEX SIMULATIONS RAPIDLY USING MATRIX_x -- THE SPACE STATION REDESIGN

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ABSTRACT

MSFC's quick response to the Space Station redesign effort last year required the development of a computer simulation to model the attitude and station-keeping dynamics of a complex body with rotating solar arrays in orbit around the Earth. The simulation was written using a rapid-prototyping graphical simulation and design tool called MATRIX_x, and provided the capability to quickly remodel complex configuration changes by icon manipulation

using a mouse. The simulation determines time-dependent inertia properties, and models forces and torques from gravity-gradient, solar-radiation, and aerodynamic disturbances. Surface models are easily built from a selection of beams, plates, tetrahedrons, and cylinders. An optimization scheme was written to determine the torque equilibrium attitudes that balance gravity-gradient and aerodynamic torques over an orbit, and propellant-usage estimates were determined. The simulation has been adapted to model the attitude dynamics for small spacecraft.

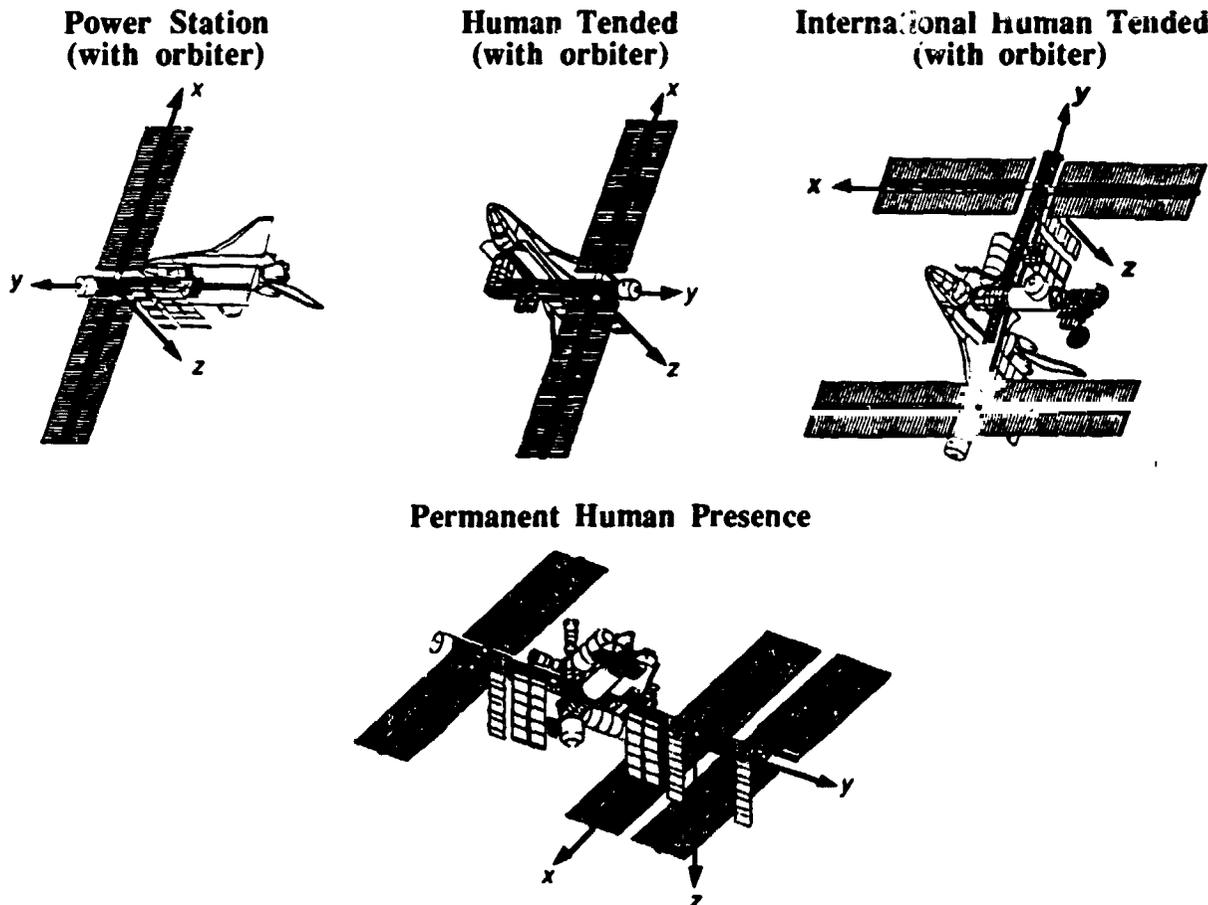


Figure 1. Option A modular-build configurations

INTRODUCTION

In early 1993, NASA was directed to present redesign options for Space Station *Freedom* that would reduce cost while maintaining science and research objectives and international commitments. The Option A design developed by the MSFC Redesign Team was a modular concept consisting of four build phases from a Power Station capability to a Permanent Human Presence facility (Fig. 1). Each configuration has the capability of berthing or jocking the orbiter for assembly and resupply. Option A also included an assessment of the Lockheed Bus-1 for guidance, control, and propulsion.

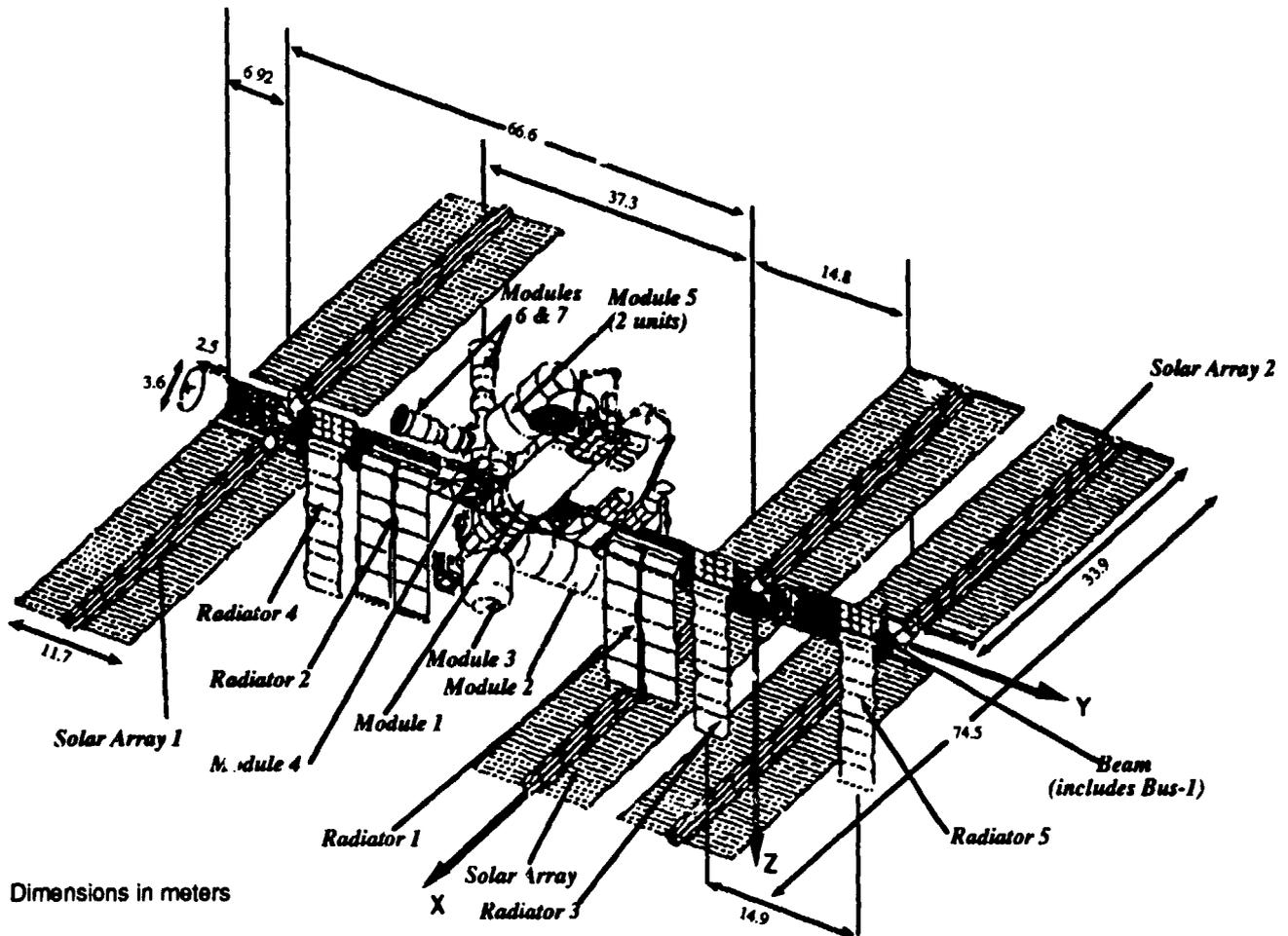
SIMULATION DEVELOPMENT

The configurations shown in Fig. 1 developed over a period of three months, with many different module patterns, solar array and radiator configurations, and flight orientations. To provide a flexible tool with quick turnaround for new configurations, a computer simulation to model the attitude and station-keeping dynamics was written using SystemBuild in MATRIX_x. This is a rapid-prototyping graphical simulation and design tool that the Preliminary Design Office runs on a SUN SparkStation, and provides the capability to quickly remodel complex configuration changes by icon manipulation using a mouse.

Three degree-of-freedom orbit dynamics and three degree-of-freedom rigid-body attitude dynamics are simulated using time-dependent inertia properties, with forces and torques from gravity-gradient, solar radiation, and aerodynamic disturbances. A simple central force model is used, and a Jacchia density model in Fortran is linked to the MATRIX_x executable. Launch dates from the flight schedule are used to determine the 2σ values for the mean solar flux and geomagnetic activity index, for input to the Jacchia density model. Icons representing beams, cylinders, plates, and tetrahedrons may be selected by the user to model the solar radiation pressure and aerodynamic drag forces and torques. Each component is represented by three lengths, six center-of-pressure locations (with respect to the component geometric center),

and a three-dimensional offset vector for the component geometric center with respect to the station's coordinate origin. Component orientation is specified by the order given for lengths, in which the first length corresponds to the station x-axis, etc. Special orientations, such as that used to orient the tetrahedron representing the orbiter, use a rotation matrix icon. Rotating components such as solar arrays are specified by their orientation when the rotation angle is zero. Cylindrical surfaces are represented by 36 flat surfaces, with contributions only from those surfaces with a positive normal component to either the wind velocity or the sun vector. A zero center-of-pressure value indicates a connection surface between components. Aerodynamic shadowing has not been modeled at this time, although efforts are underway to add simple finite element modeling capability to approximate shadowing effects. All forces and torques on surfaces are vectorially summed to produce component force and torque vectors, which are then summed over all components.

An example of component breakdown for a particular configuration is shown in Fig. 2, with the corresponding SystemBuild block diagram that sums component forces and torques in Fig. 3. All parameters that could change as the design changes have been stored by name on the stack, and their current values are loaded automatically into the pertinent simulation blocks at execution time. Hence the stack becomes the central information center for parameters such as mass, dimensions, locations, altitude and launch dates. An initialization script in the MATRIX_x language is run to define initial state values such as position and velocity, which are then substituted into the simulation. The configuration is easily changed by adding or deleting component superblocs with the mouse. Special tests, such as simulating the dynamics with no disturbance torques, are easily accomplished by substituting a zero signal in the connection from the torque outputs to the block of equations of motion. Output channels from the simulation store a time history of states and parameters such as attitude rates and angles, which can then be easily analyzed or plotted.



Components

- Solar array components are 2-array pair
- Radiators 1 and 2 are 6.8m x 15.3 m
- Radiators 3 thru 5 are 15.4m x 3.4 m
- Module 1 is Lab (8.7m x 4.4m), JEM(10.5m x 4.4m), and "Backporch" (9.9m x 7.8m)
- Module 2 is APM, 11.6m x 4.4m
- Module 3 is 4.4m x 4.4m
- Module 4 is Hab, 8.7m x 4.4m
- Module 5 is two Closet Modules
- Modules 6 and 7 are ACRVs, 7.0m x 2.2m

Figure 2. Component breakdown into cylinders, beams, and plates for aerodynamic and solar radiation modeling

TORQUE EQUILIBRIUM ATTITUDE DETERMINATION

The simulation was used to determine the Torque Equilibrium Attitudes (TEAs) that each station configuration flies. A TEA is an attitude at which the torques are balanced, and the rate of momentum buildup in the attitude control system is reduced. If no control moment gyro (CMG) torques are applied, the station would oscillate in a complex manner and the resulting motion would destroy the micro-gravity environment, as well as prohibit the orbiter from docking. If control torques were applied to hold the station in a perfect local-vertical-local-horizontal (LVLH) attitude, then the large gravity-gradient and aerodynamic disturbance torques would cause the CMGs to saturate to their maximum momentum capability, requiring RCS propellant usage or

deviations from the specified attitude. Hence a large asymmetric spacecraft like the space station must fly at a torque equilibrium attitude that does not allow the momentum to grow over time. This occurs when the torque profile has equal positive and negative areas under the curve, so that the orbital average is zero. The momentum will then be cyclic and bounded.

The TEAs discussed here are the constant angles flow... to minimize the momentum growth over one orbit. The simulation is written so that "perfect" control torques to hold a specified attitude are applied, which balance the external and gyroscopic torques. In a complete simulation of the station dynamics, these torques would be provided by dynamic models of the CMGs. The momentum required by these control torques is integrated over an orbit, and is used as a cost function for the optimization.

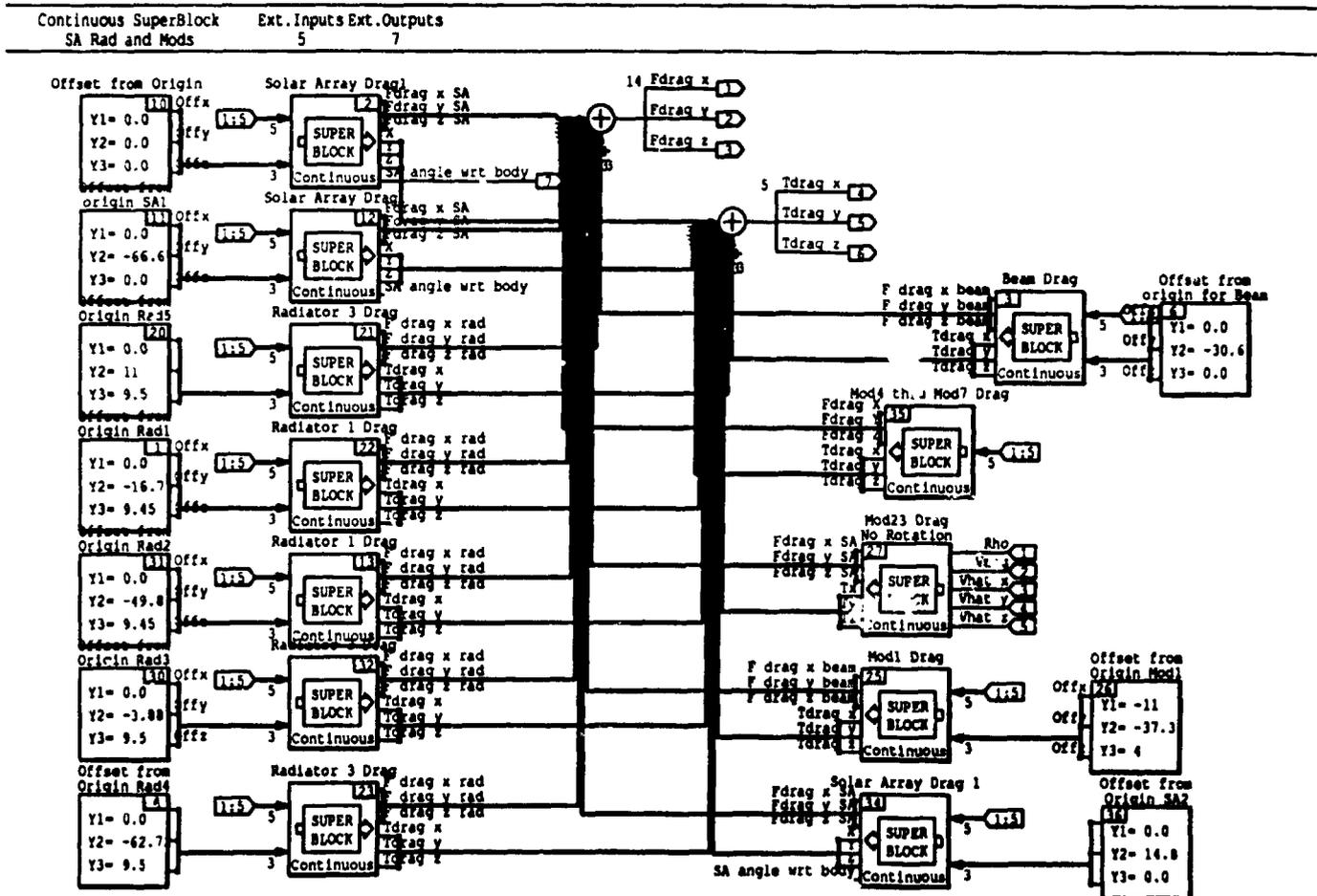


Figure 3. SystemBuild forces and torques block diagram

Several methods were explored for determining the attitude that minimizes the secular momentum. These included the nonlinear programming algorithm used in the OPTIMIZE command in MATRIX_x [1], and Powell's method, which was adapted from the Fortran codes in Press et al. [2] and rewritten as MATRIX_x executable files. Both of these techniques are multivariable optimization

algorithms that minimize a scalar cost functional, which in this case was the sum of the three orbital momentum components. A typical surface profile of this cost functional is shown in Fig. 4, in which roll and yaw angles are varied slightly around the TEA. The application of these algorithms was investigated by Thompson [3] during the 1993 Summer Faculty Fellow Program.

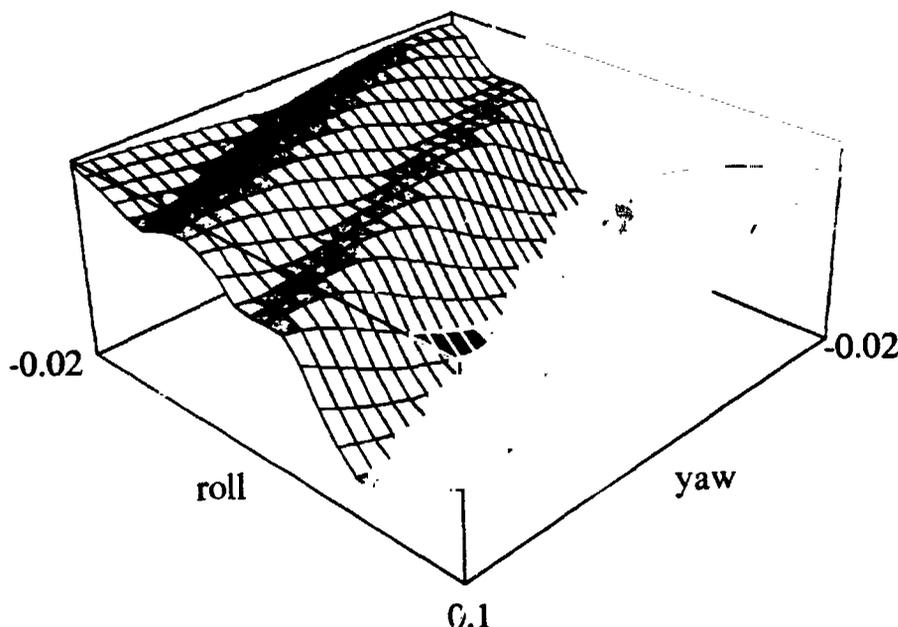


Figure 4. Scalar cost functional for variations in roll and yaw angles

The optimization algorithm discussed here was developed by Glaese and Kennel for Skylab reentry [4], and was applied in Fortran to some of the station configurations shown here by Glaese [5]. The results shown in this paper used a MATRIX_x executable with the SystemBuild simulations. This algorithm uses Newton's method to find the attitude which minimizes the vector of orbital-averaged momentum. The Jacobian is determined numerically by integrating the simulation for each perturbation of the three attitude angles. By starting with the attitude that minimizes the gravity-gradient torques, the algorithm usually converges within five iterations. Results are presented for the configuration shown in Fig. 2, flying in an "arrow" mode with the y-axis along the velocity

vector and the x-axis along the orbit normal. The inertia properties for this configuration are given in Table 1. The 1-2-3 Euler angles representing the TEA are -22.7° about the x-axis, 1.02° about the y-axis, and -88.7° about the z-axis. (This flight configuration is referenced using the LVLH flight orientation of Space Station *Freedom*, in which the x-axis is nominally along the velocity vector, the y-axis is along the orbit normal, and the z-axis is nadir. Hence the approximate -90° yaw angle puts the Bus at the back of the station.) The corresponding control momentum and torque profiles are shown in Fig. 5. The momentum required for this constant TEA lies within 7000 Nms, which is the Bus-1 capability using six CMGs. This margin could be significantly improved by removing the large

negative bias, which could be accomplished by a yaw-bias steering law like that discussed by Kelly [6].

mass	229890 kg
cg location (from PV origin)	0.72i -28.7j -0.11k m
I_{xx}	$7.7635 \times 10^7 \text{ kg m}^2$
I_{yy}	$2.0362 \times 10^7 \text{ kg m}^2$
I_{zz}	$7.0797 \times 10^7 \text{ kg m}^2$
I_{xy}	$-0.0501 \times 10^7 \text{ kg m}^2$
I_{xz}	$-0.3404 \times 10^7 \text{ kg m}^2$
I_{yz}	$-0.1164 \times 10^7 \text{ kg m}^2$

Table 1. Mass properties of PHC without orbiter

CONCLUSIONS

A graphical simulation and design tool using SystemBuild in MATRIX_x was developed for modeling the attitude and orbital dynamics of complex rigid body spacecraft. Gravity-gradient, solar-radiation pressure, and aerodynamic disturbances are modeled by user-assembled icons of beams, plates, cylinders, and tetrahedrons. Configurations from the Space Station Option A redesign effort were flown to determine propellant usage during maneuvers and orbiter docking. An optimization scheme was applied to determine orbital average TEAs, in which the secular momentum determined from the simulation was minimized. The simulation tool has been adapted to model the attitude dynamics and environmental disturbances for small spacecraft in elliptical orbits.

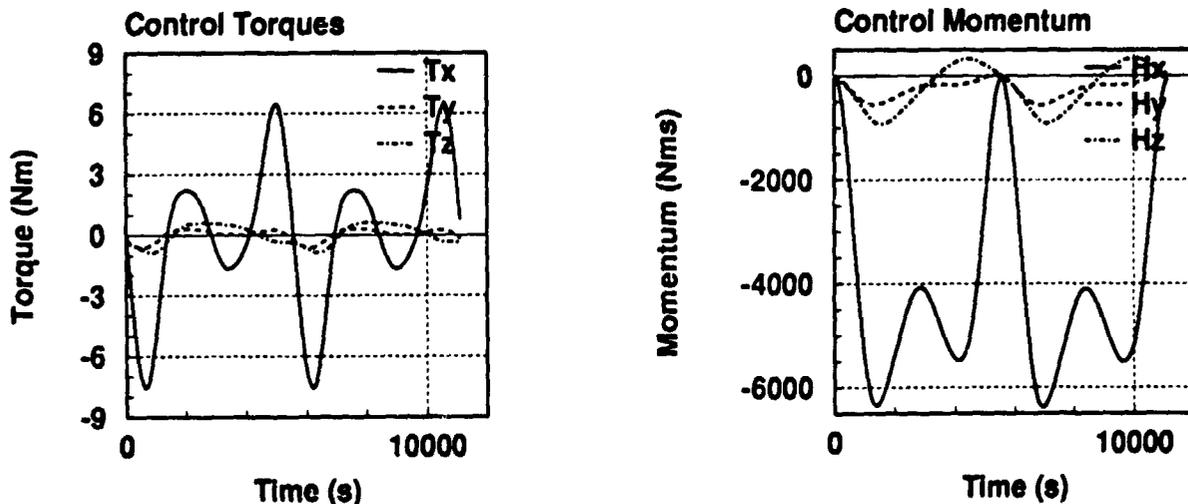


Figure 5. Momentum and torque profiles over two orbits for a constant TEA

REFERENCES

1. Integrated Systems, Inc., "MATRIX_x Optimization Module," Edition 3 - June 1991, MDG008-061.
2. Press, William H., Brian P. Flannery, Saul A. Teukolsky, and William T. Vetterling, "Numerical Recipes: The Art of Scientific Computing," Cambridge University Press, New York, New York, 1986, pp. 274-301.
3. Thompson, Roger C., "Torque Equilibrium Attitudes for the Space Station," Summer Research Program Final Report, Aug. 1993.
4. Glaese, John R. and Hans F. Kennel, "Torque Equilibrium Attitude Control for Skylab Reentry," NASA TM-78252, MSFC, Nov. 1979.
5. Glaese, John R., "Momentum Management Studies Final Report," Logicon Control Dynamics Contract No. H-78572B, MSFC, Nov. 1993.
6. Kelly, J.J., "Optimum Yaw-Biasing for Arrow Mode," Memorandum A95-J845-M-9102083, May 15, 1991.